Two Way Satellite Relaying For Self Interference Cancellation Using Weibull Distribution Under Estimated Channel Gains

Akshaya C, Amrutha Babu, Kirthika E, Felcy Jeba Malar

Abstract: in this project, we investigate the two-way satellite relaying (TWSR) system with 2 antennas at Base Stations [BSs]. The satellite used is a bend-pipe satellite which receives signals over the uplink and broadcasts these signals with some transponder gain. The signal undergoes self interference during transmission which can be overcome by having perfect knowledge of the uplink and downlink Earth Stations [ESs]. But this knowledge about the uplink and downlink ESs are difficult to produce due to reciprocity issue and transmit power limitations. So, we investigate the Channel State of Information (CSI) with Weibull Distribution and found that the design of training protocol for two-way satellite relaying is in correct state under the practical involvement of CSI estimation. We even found that both the ESs transmits orthogonal training sequence which fulfils the value of CSI for self-interference cancellation. With the help of analytically demonstrated effect of CSI estimation with Weibull Distribution over the performance of the TWSR system, we obtain reduced bit error rate and average capacity of the scheme.

Keywords: component: channel state of information, weibull distribution,two way satellite relaying, orthogonal training sequences

◆

I. INTRODUCTION

Satellite communications has a wide band transmission capability, large coverage area, and provides navigation. Satellites provide ubiquitous broadband coverage of over a large area of thousands of square kilo meters, which is used for disaster recovery. [1]- [3] A Signal latency is one which is the delay between requesting a data and the receiving of a response. In one-way communication, latency is between the actual moment of a signal's broadcast and the time the signal gets received at its destination. The distance travelled and the speed of light determines the amount of latency. The signal latency is negligible in terrestrial networks; but in satellite communications there is a problem associated with signal latency. Satellite communications has a very high latency because the signal has to travel a very long distance (for example, 35,786 km for a geostationary earth orbit (GEO) satellite) to a satellite orbit and it comes back to Earth [35]. The oldest wireless cooperative relaying communication system existing today is probably the satellite communication. In all the satellite communications, the satellites act as a relaying node which is situated very far from the earth in free-space in all the satellite communications. The satellite receives signals from the earth station over the uplink channel and forwards those signal to the destination earth station [4]-[8]. In satellite communications the bent-pipe satellites are mostly used. These satellites are less in weight, low in cost and it is of smaller size. The Bent pipe satellite receives signals at a high frequency over the uplink and down-converts the received signals to a lower frequency of the downlink, after amplifying the baseband signal by using transponder gain.

The amplify-and-forward (AF) protocol which is used for terrestrial cooperative networks is similar to this type of operation [9], [10]. The amplify and forward relaying protocol based satellites are mostly used because they process as a repeaters; whereas, the decode-and-forward relaying protocol based satellites needs complex circuitry and it is heavier in weight when compared to the amplify and forward based satellites. On considering the satellite systems, computational complexity and simple circuitry plays a vital role because higher processing at the terminal of the satellite requires high power, whereas the size of transponder will keep on increasing that results in increase in the weight and cost of the satellite system. The Decode and forward protocol has a de-noising property so that on board processing satellites are desirable but in most of the cases non regenerative satellite systems are used [21]. The regenerative satellites that is decode and forward protocol based satellites are used for only a limited case such as military and emergency services [3]. The satellite coverage area is limited due to the rain, fog, snow, poor angle of inclination, non-availability of line-of-sight (LOS), and less power transmission by the effect of masking between the satellite and a terrestrial user. The indoor users are affected by the effect of masking. A two-way satellite relaying is one where there is an exchange of data between two earth stations via a single antenna amplify-and-forward (AF) satellite relay [12]-[15]. Two terrestrial users can exchange their signals in two orthogonal time-slots/phases through a terrestrial relaying node in the two-way AF relaying. In satellite communication systems, the two-way amplify and forward relaying is favorable which reduces the latency involved in the transmission of the data between two earth stations because it make use of only half the number of time slots when compared with one way relaying [16]. This process is divided into two phases. In the first phase, the relay simultaneously access by both users which is also called as multiple access phase. In the next phase, the relay forwards whatever it has received during the first phase to both users. On the other side, if two users need to exchange their data by using one-way relaying, then it requires four phases/time-intervals. But in two-way relaying, it spends half number of time slots between two users. The uplink and downlink channels are nonreciprocal in satellite communication systems so it is difficult to generate the information of all links

---

- Akshaya C, Amrutha Babu, Kirthika E, Felcy Jeba Malar
- Asst. Professor, KCG College of Technology, ECE Department, Chennai, India
- shinyakshaya8.ca@gmail.com, sreeku7768@gmail.com, kirthiisai@gmail.com, felcy.ece@kcgcollege.com

in the ground receiver in two-way satellite relaying. It is assumed that each earth station contains the exact knowledge of channel gains required for the cancellation of self-interference and decoding the data transmitted by the other earth station. Because of atmospheric fluctuations, the satellite links vary faster than terrestrial links and it is difficult to exactly track the uplink channels in the earth station due to high signal latency. In order to avoid the problem of channel state information (CSI) estimation for self-interference cancellation and symbol detection, a differential modulation based Two Way Satellite Relaying scheme is proposed .If the exact channel state information estimate is available in the earth station, then the error performance of the two way relaying satellite scheme can be improved. Therefore, it is imperative to study the Two Way Satellite Relaying with estimated Channel State Information. Since Channel State Information estimation is a big problem in the satellite systems, it is also desirable to propose a training scheme design for the Two Way Satellite Relaying systems. Here, the two-way amplify and forward satellite communication in detail. A training protocol suitable for the practical satellite presuppositions is proposed based on the maximum-likelihood (ML) decoder of the two-way relayed data in ESs.

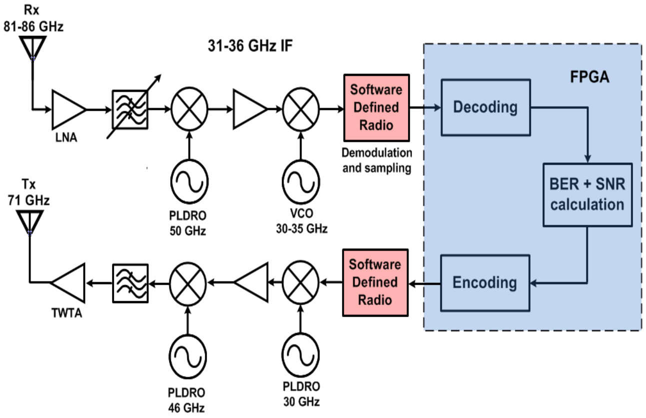
$$\hat{s}_j = \arg min\,|y_i - aG_i s_i - aG_{i,j} s_j|^2 \;\; s_j$$

Mean square error (MSE) in the Channel State Information estimation and peak-to-average power ratio (PAPR) optimal training sequences for both earth stations are determined. The training symbols are embedded in the beginning of each frame to be transmitted by each earth station. The main feature of the proposed method based on Two Way Satellite Relaying is that it does not need any feedback of the uplink Channel State Information estimates from the satellite; hence, the proposed scheme does not require any modification in the existing satellite nodes. Further, the closed-form expression of the average bit error rate (BER) and average capacity of the proposed scheme over the Shadowed Rician fading links is derived. These analytical expressions help in understanding the practical behavior of the scheme with a wide variety of the parameters like training length and Shadowed-Rician (SR) fading scenarios. The rest of the paper is organized as follows. In Section II the performance analysis containing system model self-interference cancellation and Weibull distribution is studied. In Section III, we calculate the numerical performance using the formula. Graphical results are discussed in Section IV. Section V contains a tables for the comparison works the Bit Error Rate and average capacity analysis is conducted in this Section. Later in this Section we discuss the description of the above table VI and some useful conclusions for the work presented are drawn in Section VII.

II. PERFORMANCE ANALYSIS:

A. SYSTEM MODEL:

A transponder satellite receives the signal over the range of uplink frequency from one of the ground station, amplifies them and broadcasts them over different sets downlink frequencies to the other ground station/ earth station [27]. The various electrical components in the satellite work together to create an RF communication channel of standard bandwidth (e.g. 36MHz) [28]. We worked our project in the Ku band. Ku band is the 12-18GHz portion of the electromagnetic spectrum in the microwave frequency range. The uplink and downlink frequency for a Ku band is 14GHz and 12GHz respectively.



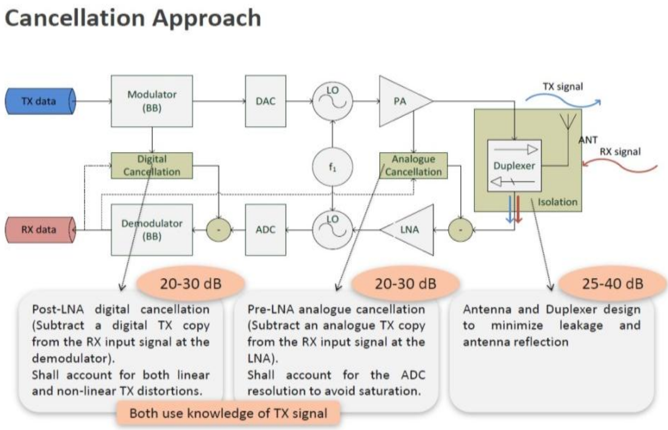
The system is assumed to work for Ku-band. For this to function perfectly further two more assumptions are made. First, only one of the two earth stations transmits signal at a given time. Secondly, even if 2 different signal frequencies are used, it is assumed that they all travel in single frequency. The signal is transmitted over the uplink frequency and received at the satellite antenna. The received signal is the passed to the LNA (Low Noise Amplifier. The signal is the passed through a filter and moves through 2 stages for down conversion. In the first stage the signal is passed through a 50GHz Phase- Locked Dielectric Resonant Oscillator (PLDRO) to bring down the signal frequency to a particular range. In the second stage the initially down-converted signal is passed through a Voltage Control Oscillator (VCO) to bring the signal frequency to 1GHz range. The software defined radio is used to demodulate the down-converted signal and to perform analogy-to-digital conversion. The digital data hence obtained can be used to for BER-SNR calculation, encoding-decoding and de-multiplexing. The decoded signal (decoding performed via forward error calculation (FEC)) from FPGA undergoes BER calculation and is re-encoded. This re-encoded signal is then again passed through the software defined radio to convert it to analog signal. This analog signal is then passed to 2 stages of PLDRO and VCO for up conversion of signal frequency. This up converted signal is then passed through a travelling wave tube amplifier instead of a solid state device due to their capability to produce high output powers. This signal is then transmitted to earth station via satellite transmitting antenna. [28]

B. SELF INTERFERENCE CANCELLATION:

A transmitted signal from the source, is cancelled at the receiver, where the desired signal is extracted from the composite signal at the receiver along with some noise. The invention has an advantage is that the user exactly prior knows the exact structure of the source transmitted signal [22]. Self-interference suppression, in general, causes a decrease in the bandwidth of the residual self-interference channel. Therefore adding an active self interference cancellation will handle a frequency-selective self-interference signal. [23]. in an amplify and forward protocol with self interference cancellation, the degradation of performance can be reduced when channel gain increases. [38]. The transmission protocol of AF two-path relaying scheme within two consecutive time slots is depicted in Fig. 1. Let yrj (i) and yd (i) denote the received signal at j-the relay, $j \in \{1, 2\}$, and received signal at D, at time slot i respectively. At time slot 1, x (1) is sent from S. Thus at R1 and D,

$yr1$ (1) = $\sqrt{\rho}$ $hs, r1x$ (1) + $nr1$ (1), (1)
yd (1) = $\sqrt{\rho}$ hs, dx (1) + nd (1), (2)

Where ρ, $hs, d \sim \mathcal{CN}$ (0, $\gamma 2$ s, d), and $hs, rj \sim \mathcal{CN}$ (0, $\gamma 2$ s, rj) are the average transmit power, the channel coefficients from S to D and S to j-th relay respectively. nrj $(i) \sim \mathcal{CN}$ (0, $\sigma 2$) and nd $(i) \sim \mathcal{CN}$ (0, $\sigma 2$) are the additive white Gaussian noise (AWGN) at the j-th relay [29].



Repeaters in particular could be an attractive solution for future wireless systems due to their typically lower processing complexity and HW requirements relative to other two-hop schemes, as well as their short forwarding delay [25]. In contrast to the existing literature, which assumes perfect self-interference cancellation, we consider imperfect self-interference cancellation at both sources that exchange information through multiple relays, and maximal-ratio combining is then applied to improve the decision statistics under imperfect signal detection. [26].

C. WEIBULL DISTRIBUTION:

Weibull Distribution is a continuous probability distribution. It is now the world's most popular method to analyses the failure data analysis and in the field of reliability engineering. It has lesser probability error than other distributions. The Probability Density Function of Weibull Distribution is given by:

$$p_X(X) = \frac{v}{w} x^{v-1} e^{\frac{-x^v}{w}}, x > 0 \qquad (3)$$

CI. NUMERICAL CALCULATIONS

$$y_s = \sum_{i=1}^{2} h_i s_i + w_s \qquad (4)$$

$$y_i = a g_i y_s + w_i \qquad (5)$$

Where ws represents the additive white Gaussian noise (AWGN) at the satellite, containing zero mean complex Gaussian noise elements with σ 2s variance; si is the symbol of ES-i from M-PSK constellation with Es energy; h_i denotes the uplink channel coefficient of ES-i .

$$snr1 = 10.\hat{}(snr/10) \qquad (6)$$

All channel gains are modeled as SR fading channels. The Probability distribution function (PDF) of |gi |2 is given by [26]

$$f_{|g_i|^2}(x) = a_i e^{-\beta_i x} 1F1(m_i; 1; \delta_i x), x > 0 \qquad (7)$$

Where i = 0, 1, α i = 0.5(2bimi / (2bimi + _i)) mi /bi, β i = (0.5/bi), δ i = 0.5_i/ (2b2 i mi + bi_i), the parameter _i is the average power of LOS component, 2bi is the average power of the multipath component, and 0 ⩽ mi ⩽ ∞ is the Nakagami parameter, for mi = 0 and mi = ∞, the envelope of hi follows the Rayleigh and Rician distribution, respectively; and 1F1 (a; b; z) is the confluent Hypergeometric function [27, eq. (9.210.1)].

$$y_i = a g_i h_i s_i + a g_i h_j s_j + a g_i w_s + w_i \qquad (8)$$

Since w_s and w_i, the Conditional pdf is given by, the decision metric of the symbol s_j is given by the ML detector mentioned above

$$\hat{s}_j = \underset{s_j}{arg\ min} |y_i - aG_i s_i - aG_{i,j} s_j|^2 \qquad (9)$$

The signals received in the ES-i during the training period (k = 1, L) can be written by using

$$z_i^{(k)} = aG_i p_k + aG_{i,j} q_k + a g_i w_s + w_i \qquad (10)$$

$$y_i^{(n)} = aG_i s_i^{(n)} + aG_{i,j} s_j^{(n)} + a g_i w_s^{(n)} + w_i^{(n)}$$

The Moment Generating Function [MGF] based approach is used to derive the average capacity. For the considered earth station ES-i, the average capacity using MGF approach is given as

$$C_i = \frac{B}{ln2} \sum_{n=1}^{N} v_n U_1(s_n) \left\{ \frac{\delta}{\delta s} M_{\gamma i}(s) \Big| s \to s_n \right\} \qquad (11)$$

Here B represents bandwidth

The expression for s_n and v_n is used in the above equation

$$s_n = \tan\left(\frac{\pi}{4} \cos\left(\frac{2n-1}{2N}\pi\right) + \frac{\pi}{4}\right)$$

$$v_n = \frac{\pi^2 \sin\left(\frac{2n-1}{2N}\pi\right)}{4N\cos^2\left(\frac{\pi}{4}\cos\left(\frac{2n-1}{2N}\pi\right) + \frac{\pi}{4}\right)} \qquad (12)$$

$U_1(s_n)$ is represented in the form of Meijer-G function

$$U_1(s_n) = -G_{2,1}^{0,2}\left(\frac{1}{s_n}\middle|\begin{matrix}1,1\\0\end{matrix}\right)$$

The conditional MGF is given by

$$M_{\gamma_i|\gamma}(s) = \tilde{\alpha}_j \sum_{l_j=0}^{\tilde{c}_j}\binom{\tilde{c}_j}{l_j}\tilde{\beta}_j^{\tilde{c}_j-l_j} \times \left(\begin{matrix}\Phi^{-(\tilde{d}_j-l_j)}(s,y)\left(1+\left(\tilde{\beta}_j-\tilde{\delta}_j\right)\Phi^{-1}(s,y)\right)^{-\tilde{d}_j}+\\ \tilde{\epsilon}_j\tilde{\delta}_j \times \Phi^{-(\tilde{d}_j-l_j-1)}(s,y)\left(1+\left(\tilde{\beta}_j-\tilde{\delta}_j\right)\Phi^{-1}(s,y)\right)^{-(\tilde{d}_j+1)}\end{matrix}\right)$$

Where $\Phi(s,y)$ is given by,

$$\Phi(s,y) = \frac{y\tilde{\gamma}s}{(y+c)\left(1+\frac{2E_s}{a^2 s}\right)} \qquad (13)$$

The conditional MGF is averaged, where the MGF of γ_i is derived and it is given by equation (14)

$$M_{\gamma_i}(s) \cong \frac{\alpha_i\tilde{\alpha}_j}{(\tilde{\beta}_j-\tilde{\delta}_j)^{\tilde{d}_j}}\sum_{l_j=0}^{\tilde{c}_j}\binom{\tilde{c}_j}{l_j}\tilde{\beta}_j^{\tilde{c}_j-l_j}\sum_{l_i=0}^{c_i}\binom{c_i}{l_i}\beta_i^{c_i-l_i} \times \left(\frac{s\bar{\gamma}}{\left(1+\frac{2E_s}{a^2S}\right)}\right)^{l_j}\left(\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\epsilon_i\delta_i \times \mathcal{J}\left(l_i,d_i+1,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\frac{\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\times\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)+\frac{\epsilon_i\delta_i\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\mathcal{J}\left(l_i,d_i+1,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)\right)$$

In this , $\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right)$ is given by equation (15)

$$\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right) = \sum_{m=0}^{\tilde{d}_j-l_j}\binom{\tilde{d}_j-l_j}{m}\frac{\vartheta_{j,k}^{-(l_j+m+d_i-l_i)}}{\Gamma(d_i)\Gamma(\tilde{d}_j)c^{l_j+m}} \times G_{23}^{22}\left(\frac{\beta_i-\delta_i}{\vartheta_{j,k}}\middle|\begin{matrix}1-d_j,1-\left(l_j+m+d_i-l_i\right)\\0,\tilde{d}_j-l_j-m-d_i+l_i,1-d_i+l_i\end{matrix}\right)$$

And

$$\vartheta_{j,k} = \frac{s\bar{\gamma}+\left(1+\frac{2E_s}{a^2S}\right)(\tilde{\beta}_j-\tilde{\delta}_j)}{\left(1+\frac{2E_s}{a^2S}\right)(\tilde{\beta}_j-\tilde{\delta}_j)c} \qquad (16)$$

Then the derivative of first order of $\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right)$ can be given as equation (17)

$$\mathfrak{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right) = \frac{\delta}{\delta s}\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right) = \sum_{m=0}^{\tilde{d}_j-l_j}\binom{\tilde{d}_j-l_j}{m}\frac{(\beta_i-\delta_i)^{-(l_j+m+d_i-l_i)}}{\Gamma(d_i)\Gamma(\tilde{d}_j)c^{l_j+m}} \times \frac{-\vartheta_{j,k}^{-1}\bar{\gamma}}{\left(1+\frac{2E_s}{a^2S}\right)\left(\tilde{\beta}_j-\tilde{\delta}_j\right)c} \times G_{34}^{23}\left(\frac{\beta_i-\delta_i}{\vartheta_{j,k}}\middle|\begin{matrix}0,1+l_j+m-l_i,1\\l_j+m+d_i-l_i,1+l_i+m,1\end{matrix}\right)$$

The first order derivative of MGF is given as

$$\frac{\delta}{\delta s}M_{\gamma_i}(s) = \frac{\alpha_i\tilde{\alpha}_j}{(\tilde{\beta}_j-\tilde{\delta}_j)^{\tilde{d}_j}}\sum_{l_j=0}^{\tilde{c}_j}\binom{\tilde{c}_j}{l_j}\tilde{\beta}_j^{\tilde{c}_j-l_j}\sum_{l_i=0}^{c_i}\binom{c_i}{l_i}\beta_i^{c_i-l_i} \times l_j s^{l_j-1}\left(\frac{\bar{\gamma}}{\left(1+\frac{2E_s}{a^2S}\right)}\right)^{l_j}\left(\begin{matrix}\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\epsilon_i\delta_i\times\\ \mathcal{J}\left(l_i,d_i+1,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\\ \frac{\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\times\mathcal{J}\left(l_i,d_i,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)+\\ \frac{\epsilon_i\delta_i\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\mathcal{J}\left(l_i,d_i+1,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)\end{matrix}\right)$$

$$+\frac{\alpha_i\tilde{\alpha}_j}{(\tilde{\beta}_j-\tilde{\delta}_j)^{\tilde{d}_j}}\sum_{l_j=0}^{\tilde{c}_j}\binom{\tilde{c}_j}{l_j}\tilde{\beta}_j^{\tilde{c}_j-l_j}\sum_{l_i=0}^{c_i}\binom{c_i}{l_i}\beta_i^{c_i-l_i} \times \left(\frac{s\bar{\gamma}}{\left(1+\frac{2E_s}{a^2S}\right)}\right)^{l_j}\left(\begin{matrix}\mathfrak{J}\left(l_i,d_i,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\epsilon_i\delta_i\times\\ \mathfrak{J}\left(l_i,d_i+1,l_j,\tilde{d}_j,\vartheta_{j,k}\right)+\\ \frac{\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\mathfrak{J}\left(l_i,d_i,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)+\\ \frac{\epsilon_i\delta_i\tilde{\epsilon}_j\tilde{\delta}_j}{\tilde{\beta}_j-\tilde{\delta}_j}\mathfrak{J}\left(l_i,d_i+1,l_j,\tilde{d}_j+1,\vartheta_{j,k}\right)\end{matrix}\right) \qquad (18)$$

For an average capacity to be calculated, the transmission bandwidth of the satellite is deduced to be 36 MHz which lies in L, C, Ku, and Ka band within the enumerated bandwidth. For different values of SNR, the analytical values of capacity in bits per second (bits/sec) are calculated by using equation 1 and equation 2. Here, the training length L varies from 2 to 10 in steps of 2. The average capacity of the TWSR system has a very accurate analytical expression. Due to the small value of the training length the capacity of the TWSR scheme is affected severely. By using the training length L=10 ,the capacity loss can be reduced further when compared with the training length L=2.On considering a 11dB SNR the considered scheme loses about 46% capacity with L=2 but when compared with L=10 at 11dB the capacity loss is further reduced approximately to 14%.SNR .A very large value of capacity can be achieved in this training based TWSR scheme of 7.4 Megabits per seconds with training length of L = 10 at 12 dB SNR under FHS/FHS fading scenario.

IV. GRAPHICAL RESULTS

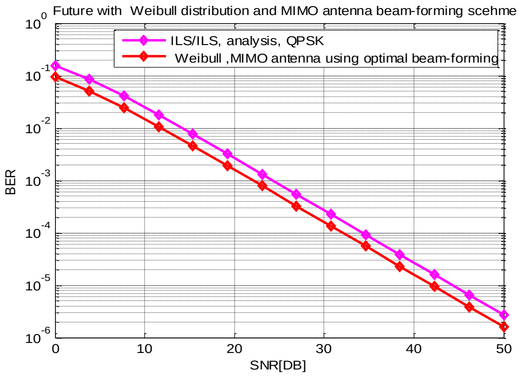


Fig1 *shows the graph of weibulldistribution in beam forming*

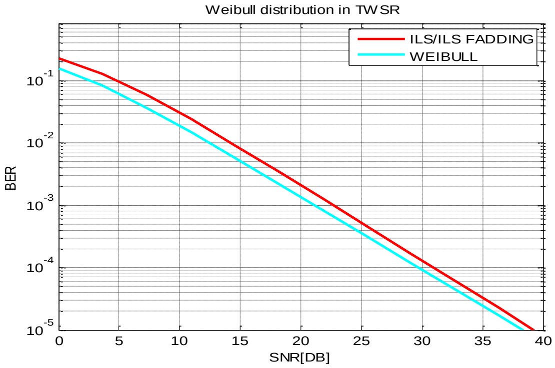


Fig2 *shows the graph of weibull in TWSR and it lower BER*

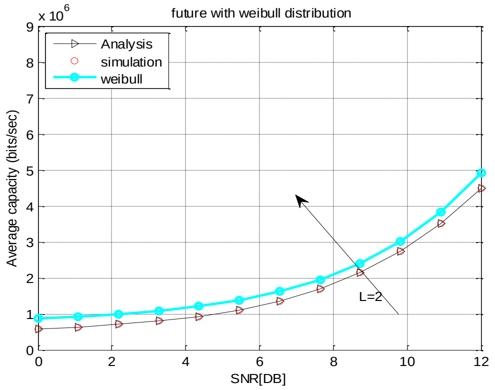


Fig3 *shows the average capacity of the channel after adding weibull*

V.TABLE – RESULTS OF THE PAPERS COMPARISON

SIMULATION RESULTS	TWSR	WEIBULL
BER vs SNR	0.1573	0.09
BER vs SNR	0.22	0.155
AVERAGE CAPACITY vs SNR	0.5853	0.8651

VI. DESCRIPTION OF TABLE

The above table shows the comparison of the two way satellite relaying system with the channel state of information is estimated. The results from the previous papers where found to be convincing to the theoretical results. In this paper, we have produced results closer and accurate to the ideal values when weibull distribution was added to it. The values in the tabulation prove that the average capacity of the channel is increased which can be able to carry more parallel data with low error rate.

VII. CONCLUSION

We have examined the problems that occur during the transmission of the signal from the ESs during transmission and reception. A training protocol has been introduced to solve problems and for estimation of imperfect CSI. The self interference effect is reduced and when we added weibull distribution the results have founded to be elevated and to be close to ideal theoretical values. Analytical expression for BER and SNR have been found based on the theoretical results. Thus from this paper we can prove that the average capacity of the channel is increased for training symbols for L=8 and L=10 in the QPSK constellation.

VIII. REFERENCES

[1] T. Pratt, C. Bostian, and J. Allnutt, Satellite Communications, 2nd ed. New York, NY, USA: Wiley, 2003.

[2] G. Maral, M. Bousquet, and Z. Sun, Satellite Communications Systems: Systems, Techniques and Technology, 5th ed. New York, NY, USA: Wiley, 2009.

[3] K. Y. Jo, Satellite Communications Network Design and Analysis. Norwood, MA, USA: Artech House, 2011.

[4] Arti M. K. and M. R. Bhatnagar, “Beamforming and combining in hybrid satellite-terrestrial cooperative systems,” IEEE Commun. Lett., vol. 18, no. 3, pp. 483–486, Mar. 2014.

[5] M. R. Bhatnagar and Arti M. K., “Performance analysis of AF based hybrid satellite-terrestrial cooperative network over generalized fading channels,” IEEE Commun. Lett. vol. 17, no. 10, pp. 1912–1915, Oct. 2013.

[6] M. R. Bhatnagar and Arti M. K., “Performance analysis of hybrid satellite-terrestrial FSO cooperative system,” IEEE Photon. Technol. Lett., vol. 25, no. 22, pp. 2197–2200, Nov. 15, 2013.

[7] Arti M. K., “Channel estimation and detection in hybrid satelliteterrestrial communication systems,” IEEE Trans. Veh. Technol., to be published, doi: 10.1109/TVT.2015.2456433.

[8] Arti M. K., “A novel beamforming and combining scheme for two-way AF satellite systems,” IEEE Trans. Veh. Technol., to be published, doi:10.1109/TVT.2016.2557352.

[9] A. Nosratinia, T. E. Hunter, and A. Hedayat, “Cooperative communication in wireless networks,” IEEE Commun. Mag., vol. 42, no. 10, pp. 74–80, Oct. 2004.

[10] Arti M. K., R. K. Mallik, and R. Schober, “Performance analysis of OSTBC relaying in AF MIMO relay systems with imperfect CSI,” IEEE Trans. Veh. Technol., vol. 64, no. 7, pp. 3291–3298, Jul. 2015.

[11] M. R. Bhatnagar, “Performance evaluation of decode-and-forward satellite relaying,” IEEE Trans. Veh. Technol., vol. 64, no. 10, pp. 4827–4833, Oct. 2015.

[12] B. Rankov and A. Wittneben, “Achievable rate regions for the two-way relay channel,” in Proc. IEEE Int. Symp. Inf. Theory (ISIT), Seattle, WA, USA, Jul. 2006, pp. 1668–1672.

[13] Arti M. K. and M. R. Bhatnagar, “Performance analysis of two-way AF MIMO relaying of OSTBCs with imperfect channel gains,” IEEE Trans. Veh. Technol., vol. 63, no. 8, pp. 4118–4124, Oct. 2014.

[14] Arti M. K., R. K. Mallik, and R. Schober, “Beamforming and combining in two-way AF MIMO relay networks,” IEEE Commun. Lett. vol. 17, no. 7, pp. 1400–1403, Jul. 2013.

[15] Arti M. K. and M. R. Bhatnagar, “Imperfect CSI based two-way AF MIMO relaying of OSTBC,” in Proc. IEEE Int. Conf. Commun. (ICC), Sydney, NSW, Australia, Jun. 2014, pp. 4430–4435.

[16] F. Gao, R. Zhang, and Y.-C. Liang, “Optimal channel estimation and training design for two-way relay networks,” IEEE Trans. Commun., vol. 57, no. 10, pp. 3024–3033, Oct. 2009.

[17] S. Abdallah and I. N. Psaromiligkos, “Exact Cramer–Rao bounds for semiblind channel estimation in amplify-and-forward two-way relay networks employing square QAM,” IEEE Trans. Wireless Commun., vol. 13, no. 12, pp. 6955–6967, Dec. 2014.

[18] C. Couvreur, “The EM algorithm: A guided tour,” in Proc. 2nd IEEE Eur. Workshop Comput. Intensive Methods Control Signal Process., Prague, Czech Republic, Aug. 1996, pp. 1–6.

[19] Arti M. K., “Channel estimation and detection in satellite communication systems,” IEEE Trans. Veh. Technol., to be published, doi: 10.1109/TVT.2016.2529661.

[20] Arti M. K., “Performance evaluation of maximal ratio combining in Shadowed–Rician fading land mobile satellite channels with estimated channel gains,” IET Commun., vol. 9, no. 16, pp. 2013–2022, Nov. 2015.

[21] Arti M. K., Member, IEEE, Two-Way Satellite Relaying With Estimated Channel gains IEEE transactions on communications, vol. 64, no. 7, july 2016 .

[22] Self interference cancellation for two-party relayed communication Inventors: Mark D. Dankberg, Encinitas; Mark J. Miller, Vista, both of Calif.; Michael G. Mulligan, Westford, Mass.)

[23] (Passive Self-Interference Suppression for Full-Duplex Infrastructure Nodes Evan Everett, Achaleshwar Sahai, and Ashutosh Sabharwal cs.IT 17 dec 2013)

[24] (AF Two-Path Half Duplex Relaying with Inter-Relay Self Interference Cancellation: Diversity Analysis and its Improvement H. Wicaksana, Student Member, IEEE, S. H. Ting, Member, IEEE, C. K. Ho, Member, IEEE, W. H. Chin, Member, IEEE, and Y. L. Guan, Member, IEEE, ieee transactions on wireless communications, vol. 8, no. 9, september 2009)

[25] (Impact of Channel Estimation Error on the Performance of Amplify-and-Forward Two-Way Relaying Chenyuan Wang ; Ted C.-K. Liu ; Xiaodai Dong IEEE Transactions on Vehicular Technology (Volume: 61, Issue: 3, March 2012)

[26] MIMO On-Frequency Repeater with Self-Interference Cancellation and Mitigation Peter Larsson, Mikael Prytz Ericsson Research, Sweden

[27] www.jsati.com/why-satellite-how-Spacesegment4.asp

[28] en.wikipedia.org/wiki/Transponder